A NEUTRON AMPLIFIER ASSEMBLY

5   This invention refers to a neutron amplifier assembly
comprising a slightly subcritical array of fissile material
which is subjected to a primary neutron flux.

A neutron flux is used not only for research purposes
10   but also for irradiating goods, for cancer treatment and
even for controlling a nuclear power generator. For example,
a high neutron intensity above 10^{17} s^{-1} would be useful for
many purposes. Such a high flux is beyond the practical
possibilities of modern accelerators, even in combination
15   with a spallation target. It is therefore an object of the
present invention to provide a neutron amplifier assembly
which supplies an intense and readily controllable neutron
flux.

This object is achieved according to the invention by
20   the neutron amplifier assembly as defined in claim 1. For
further improvements of this assembly reference is made to
the secondary claims.

The invention will now be described in detail by
means of some preferred embodiments and the enclosed draw-
25   ings.

Figure 1 shows schematically in cross-section a first
embodiment of the assembly according to the invention.

Figure 2 shows the relation between the mass and
layer thickness of fissile material in the hollow cylindri-
30   cal arrangement of given dimensions for $k_{eff} = 1$.

Figure 3 shows a variant which is conceived to
produce a high flux of fast neutrons.

Figure 4 is an improved embodiment with two
subcritical arrays in series.

35   According to a first embodiment shown in figure 1,
the fissile material is Am^{242m}. This material constitutes a

thin layer 1 on the inner surface of a hollow cylinder 2 of circular cross-section, made of a neutron moderator material such as graphite or beryllium. Along the axis of this cylinder a spallation target 3 is located which is intended to

5   receive a proton beam from an accelerator (not shown) along the axial direction of the cylinder 2. As an example, the cylinder height and its inner diameter are both 1 m, the diameter of the target 3 being 30 cm.

The thickness of the layer 1 is in the micrometer

10   range and will be specified later. This thickness depends upon the type of fissile material and its concentration in this layer. In any case it must be sufficiently small in order to allow fast neutrons to pass therethrough without interaction, whereas thermal neutrons are trapped.

15   Neutrons starting from the target 3 may be either thermal or fast neutrons.

Thermal neutrons react immediately with the layer 1 and generate fast neutrons whereas fast neutrons pass therethrough without interaction. In both cases fast neutrons

20   penetrate into the graphite cylinder 2 and become thermalized. If these neutrons penetrate again into the layer 1 they cause more fissions. Those which escape from the cylinder at its outside constitute the output of the amplifier assembly.

25   It should be noted that the thickness of the fissile material layer on the inner surface of the graphite cylinder should be such that the arrangement does not become critical, but a criticality factor k_{eff} close to 1 should be achieved in order to enhance the neutron amplification gain.

30   The tables following hereafter show, for a cylinder having an inner diameter ϕ equal to its height, the thickness of a layer of Am^{242m} and U^{235} respectively required for various inner cylinder diameters ϕ necessary to make the system critical.

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AMENDED SHEET

ϕ (cm)	critical thickness (cm)	critical mass (kg)
10	0.4	2.6
20	0.063	1.6
30	0.005	0.25
40	0.001	0.1
60	0.0004	0.08

Table 1. Layer thickness of Am^{242m} metal and corresponding mass required for criticality for various cylinder diameters ϕ.

ϕ (cm)	critical thickness (cm)	critical mass (kg)
10	2	14
20	0.8	20
40	0.15	14
60	0.023	5
100	0.007	4

Table 2. Layer thickness of U^{235} metal and corresponding mass required for criticality for various cylinder diameters ϕ.

These values are also represented in the plot of Figure 2 as small circles and crosses respectively. One can for example deduce therefrom that criticality is obtained with an Am^{242m} layer thickness of 4 µm on the inner surface (diameter 60 cm) of a graphite cylinder (axial length 60 cm). The overall critical mass of fissile material is under these circumstances only 80 g which is considerably less than the (bare) critical mass of a solid sphere of the same material (4.7 kg).

Thus if a thickness below 4 µm is chosen then the arrangement will be subcritical. If for example the criticality factor k_{eff} is 0.95 then its neutron amplification factor will become 20.

- 4 -

A commercial cyclotron supplying a proton beam of 150
MeV produces in a lead spallation target about 1 neutron per
proton. Due to the layer of fissile material this neutron
produces on average M neutrons where $M \approx 1/(1 - k_{eff})$. For the
case of $k_{eff} = 0.95$, M is approximately 20.

The invention is not restricted to the embodiment
described above. One could employ other fissile materials,
such as U^{235} (see table 2 and figure 2). It should further be
noted that the invention is also applicable to materials
others than pure fissile materials, in which the fissile
material is present in the layer at a substantially reduced
amount.

It is also possible to cover the inner layer 1 of
fissile material with a layer of moderator material in order
to reduce damages in the fissile material layer due to high
energy neutrons.

The neutron source can instead of a spallation target
consist of a neutron emitter such as Californium.

The cylinder 2 is not necessarily of circular cross-
section as shown in the drawings. In fact, the cross-section
might be square or present an inner corrugated shape like a
star. In this latter case the overall diameter of the cylin-
der 2 can be reduced whilst maintaining the same surface
area of fissile material.

The heat production in the arrangement is rather low:
Taking the above cited example of a 150 MeV accelerator
supplying a proton current of 2 mA (corresponding to 300 kW
power output) and a neutron amplification factor of 20 due
to the layer 1 of fissile material, the neutron intensity
will become about $2,5 \cdot 10^{17}$ s^{-1}. Since the neutron generation
rate is approximately equal to the rate of fissioning, the
maximum heat generation rate is about 8 MW. This heat can be
easily extracted through coolant channels in the graphite
cylinder.

In case that not a thermal neutron flux but a fast

neutron flux is desired, the arrangement according to figure
1 should be completed, as shown in figure 3, by a further
layer 4 of fissile material on the outer surface of the
graphite cylinder 2 and optionally by a metal casing 5
around this layer, especially made of tungsten. This second
layer 4 is again transparent to fast neutrons as it inter-
acts only with neutrons which have been thermalized in the
graphite cylinder. These neutrons cause fissions which
result in fast neutrons. A part of these fast neutrons
escapes through the casing whereas others return into the
graphite cylinder and cause further fissions in one of the
layers of fissile materials.

According to a further improvement of the present
invention two or more layers of fissile material are
located, preferably in a concentric axial configuration,
between the spallation target and the inner diameter of the
graphite cylinder. Such an example is sketched in figure 4.
Here, one additional layer 6 of fissile material is added
which is either self-supporting or deposited on a metal
tube, for example made of tungsten (not shown).

As a further improvement, one or more moderator rods
(not shown) can be inserted in a controlled manner into the
free space inside the graphite cylinder. This insertion
increases the criticality factor and allows a fine control
of the neutron amplification factor and of the criticality
factor, in order to take into account inhomogeneities of the
thin layers and their burn-up.